The Economics of trypanosomiasis: Empirical Evidence on Its Impacts on Livestock Production and Welfare

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Abstract

The livestock sector plays crucial roles as food, nutrition, and income sources and as an input for crop production in Ethiopia. However, the sector's productivity remains low, and livestock mortality is high because of production constraints, such as trypanosomiasis. Evidence on the impacts of production constraints on the livestock sector is a key for informed decision-making. We investigate the impacts of trypanosomiasis disease on livestock death, livestock production cost, milk yield, crop production, and its broader implications on poverty. We apply panel data methods using three rounds of data from 5,763 smallholder farmers in Ethiopia. Our findings show trypanosomiasis, on average, contributes to 33 percent value of livestock death. Households affected by this disease obtain 45 percent less milk yield and incur 68 percent higher livestock production cost. Results also reveal that households affected by trypanosomiasis are 3.7 percentage points more likely to be poor. The lost livestock value could have lifted 442,104 persons living in rural areas from absolute food poverty. These results indicate that trypanosomiasis remains a major livestock production constraint in Ethiopia.

Keywords: trypanosomiasis, livestock performance, livestock mortality, livestock cost of production, poverty

1. Introduction

Livestock plays a crucial role in reducing food insecurity, particularly in rural areas where the larger share of the extremely poor, and the food and nutrition insecure population live in (Alary et al., 2011; Asresie & Zemedu, 2015; Roy Behnke & Muthami, 2011; Bijla, 2018; Do et al., 2019; Herrero et al., 2014, 2016). The demand for livestock products has been growing in developing countries (Mayberry et al., 2017). Besides its role as a means of saving and accumulating wealth, the livestock sector plays crucial roles as buffer against crop failure and as source of income, nutrition and draught power for the rural population (Asresie & Zemedu, 2015; Roy Behnke & Muthami, 2011; Bell et al., 2021; Bijla, 2018; Do et al., 2019; Fafchamps et al., 2005; Herrero et al., 2014; Jodlowski et al., 2016; Leta et al., 2016). For instance, 80% of farmers in Ethiopia use livestock as draught power for plowing land, threshing grains and for transporting harvest in rural areas (R. Behnke, 2010; Roy Behnke & Metaferia, 2013). Moreover, the livestock dung is a key source of fuel and manure. The livestock contributes about 45% of the agricultural GDP and 25% of the overall GDP in Ethiopia, and supports about 11 million households, about a third of whom are poor (Roy Behnke & Metaferia, 2013; Roy Behnke & Muthami, 2011; Shapiro et al., 2017).

However, in addition to that the sector has been overlooked in many developing countries' policies, livestock death remains substantial, posing major threat to particularly the rural poor (Rich & Perry, 2011). For instance, about 212 million heads of livestock died in Ethiopia between 2017 and 2019 alone (CSA, 2018, 2019, 2020). The tsetse-fly-transmitted animal trypanosomiasis is one of the key neglected tropical diseases with severe socioeconomic consequences in Sub-Saharan Africa (SSA) (M. Alsan, 2015; Marcella Alsan, 2018; Murray & Gray, 1984). It causes substantial livestock death and morbidity, thereby reducing the productivity of the sector in the region (Aksoy et al., 2014; Barrett, 1989; Bouyer et al., 2013; Dransfield et al., 1991; Holmes, 2013)**.** Besides deaths of livestock, the disease causes direct losses by reducing meat and milk production, and indirect losses because of reduced fertility and draught capacity, and increasing cost of livestock production. Estimates show that about 32% of the region's livestock population are found in tsetse-fly-infested areas (Kristjanson et al., 1999), and it affects about 60 million people, and 50 million heads of their cattle (Barrett, 1989; Cattand et al., 2010; FAO, 2019). A meta-analysis of 24 studies conducted between 1997 and 2014 in Ethiopia reveal that trypanosomiasis affected about 8.12% of bovine livestock (Leta et al., 2016). The direct and indirect losses due to trypanosomiasis could reach 4-4.5 billion US$ per annum globally (Holmes, 2013). Moreover, traditionally non-tse-tse-fly areas are becoming suitable to tse-tse-fly invasions due to climate change (Longbottom et al., 2020; Lord et al., 2021; Messina et al., 2013; Moore et al., 2012). Since livestock is a source of livelihood to the majority of the poor (Staal et al., 2009) Mwiinde et al., 2017, trypanosomiasis is likely to contribute to food insecurity and poverty, but there is no estimate about this, to the best of our knowledge.

The contribution of trypanosomiasis to livestock deaths is not, however, readily available. The existing quantitative evidence on the impact of trypanosomiasis are limited due to lack of data. Moreover, some of the existing data are either fragmented or outdated (Ebhodaghe, 2020; B. D. Perry et al., 2013; Thornton, 2010; Zezza et al., 2016). Particularly, detailed information on key diseases to analyze their impact on various development outcomes are missing (B. Perry et al., 2001; Pica-Ciamarra et al., 2015; Rushton & Perry, 2018; Thornton, 2010). Indeed, several studies investigated the incidence of various diseases, biological features of diseases, and income losses due to diseases (Aksoy et al., 2014; Dransfield et al., 1991; Itty, 1991; Leta et al., 2016; Van den Bossche & Delespaux, 2011). However, most of the studies are descriptive, without disentangling the impact of the diseases from other confounding factors (Do et al., 2019; Holmes, 2013).

In an attempt to fill this research gap, we analyze a large, three rounds panel datasets to investigate the effect of trypanosomiasis on livestock death, cost of livestock production, cow milk yield, crop production measured in value terms, and its broader implication on poverty. We measure livestock death in terms of value, Tropical Livestock Units and in in terms of a dummy variable indicating whether a household lost livestock because of death. This paper contributes to the animal health economics literature in the following ways. We disentangle the direct effects of trypanosomiasis on these outcome variables. Unlike the previous studies, we use a unique household surveys panel dataset that enable us to control for unobserved heterogeneity across households such as farm managerial skills that may affect both the outcome variables and the incidence and severity of trypanosomiasis simultaneously. Second, to our knowledge, this study is the first that quantified the indirect effects of trypanosomiasis on crop production. Third, we ask if trypanosomiasis increases absolute poverty in rural households. We disaggregate the impact by severity of the disease. Finally, we investigate the wider economic impact of trypanosomiasis, and we quantify the number of persons that would had been lifted out of poverty had the country managed to control livestock death due to trypanosomiasis. Quantifying the effects of trypanosomiasis could help policymakers to design pro-poor and successful disease control programs (B. Perry et al., 2001; Rich & Perry, 2011).

Moreover, this paper may contribute to achieving the Sustainable Development Goals (SDGs), by attracting donors' and policy practitioners' attention to control and eradicate trypanosomiasis. Particularly, this paper could have direct practical relevance to policymakers of the African Union (AU), trypanosomiasis control and eradication offices, and donors who are fighting trypanosomiasis (Abro et al., 2021; FAO, 2019).

Our estimates from a conservative fixed effects models show that households whose livestock are affected by trypanosomiasis loss, on average, 83% more value of livestock death, which increases to 154% for households whose livestock are severely affected by the disease. Our results reveal also that households whose livestock are affected by trypanosomiasis obtain 69% less milk yield, incur 100% higher livestock medication expense, and they are more likely to be poor than households whose livestock are not at all affected by the disease. Under certain assumptions, the loss of livestock by the disease would had lifted up to 28.4 million persons out of absolute poverty. These estimates do not include the income and wealth losses due to the disease's impact on livestock products, cost of livestock production and on crop production. Moreover, the economic losses substantially increase with severity of the disease.

The rest of this paper is structured as follows. In Section 2, we briefly describe the data. In Section 3, we discuss the estimation methods used to quantify the economic effects of trypanosomiasis. In Section 4, we present descriptive results and summary statistics while key results from econometrics analysis is presented in Section 5. In Section 6, we conclude.

2. Data

This study uses three rounds of panel data collected by the Agricultural Growth Program of Ethiopia.[1] The survey data was collected in 2011, 2013 and 2017. The Central Statistical Authority (CSA) collected all the three rounds of surveys. The first and the second wave surveys were designed jointly by CSA, the

[1] The data was accessed through the World Bank.

Ministry of Agriculture (MOA) and International Food Policy Research Institute (IFPRI) while the last wave was designed by CSA and the Ethiopian Development Research Institute (EDRI). A total of 7,927 households from 93 woredas of the Amhara, Oromia, Tigray, and Southern Nations Nationalities and people (SNNP) Regional States of Ethiopia were interviewed during the baseline survey. Out of which, 5,763 households who have livestock in the last 12 months preceding the surveys and who were interviewed in all the three rounds are used for the analysis. The selection of samples follows a multistage sampling technique. In the first stage, 93 districts with high agricultural growth potential were selected from the four regional states. In the second stage, sample enumeration areas were randomly selected from the selected districts. Finally, households were randomly selected from the selected enumeration areas (Weldesilassie et al., 2018).

The data have rich information about crop production and livestock rearing, suitable for rigorous investigation of the dynamics of livestock production and production constraints. Unlike other surveys, the data has detail information about livestock production, constraints of livestock production including deaths of livestock disaggregated by livestock type, and about livestock and livestock products marketing and use. The datasets also contain information about the types of livestock the households owned at the time of the data collection; the number of livestock sold, slaughtered, and the number and type of livestock died in the last 12 months preceding the surveys; and the number of livestock products produced, consumed, sold and processed to add values.

The datasets have information on trypanosomiasis, which is one of the deadliest animal diseases in the country (Leta et al., 2016). The survey asks if any of the livestock of the household were affected by trypanosomiasis in the last 12 months preceding the surveys. It includes information about the severity of the disease incidence, asking the households whether their livestock were severely, moderately or not at all affected by trypanosomiasis.

Moreover, the survey contents information about all other unnamed livestock diseases other than trypanosomiasis as well as about grazing land and water shortage problems. In addition, disaggregated data on the cost of livestock production, including costs of labor, feed and medicine was collected in the last two rounds of the survey. In addition, the datasets have information on key control variables such as access, demand, and satisfaction level of extension services about livestock production; infrastructural development conditions of the districts including the type and access of markets, electricity and water access and road type; and detailed socio-economic and demographic characteristics of the households. Moreover, the large sample size and wider geographical coverage of the data provide also a substantial variation on our variables of interest, increasing the consistent of our estimates.

3. Empirical estimation strategy

This section presents the empirical specification of the effect of trypanosomiasis on death of livestock, milk production, crop production, costs of livestock production, and on poverty. The incidence of trypanosomiasis in a given area is exogenous shock to a household. Nevertheless, household socio-economics characteristics and other variables affect the infection of livestock and the severity of the impact as discussed later in this section. Thus, we estimate the effects of trypanosomiasis incidence on the outcome variables using equation (1) as follows:

$$(1) \quad \boldsymbol{Y_{it} = \alpha + \beta D_{it} + \varepsilon_{it}}$$

where $\boldsymbol{Y_{it}}$ denotes outcome variables (dependent) for household $\boldsymbol{i}$ at time $\boldsymbol{t}$. The outcome variables include livestock death, cost of livestock production, veterinary and medicine expenses, cow milk yield, and poverty status of the household. D_{it} is a dummy variable equals one if at least one of the livestock of household $\boldsymbol{i}$ were affected by trypanosomiasis at time $\boldsymbol{t}$, and equals zero otherwise. The coefficient α and β are population parameters to be estimated, and $\boldsymbol{\varepsilon_{it}}$ is error term associated with household $\boldsymbol{i}$ at time $\boldsymbol{t}$.

Trypanosomiasis is not the only factor affecting the outcome variables. Other production constraints, socio-economic characteristics of households, changes associated with time change, and other unobserved household- and district- level heterogeneities too affect the dependent variables. Similarly, livestock affected by other productions constraints are more likely to die by trypanosomiasis than livestock without other production constraints. To control for these issues, we included interaction terms of trypanosomiasis with other unnamed production constraints and trypanosomiasis with shortage of grazing land or water. Account for these issues, equation (1) is modified as

$$(2) \quad \boldsymbol{Y_{it} = \alpha + \beta D_{it} + P_{it}\delta + D_{it}P_{it}\eta + X_{it}\gamma + \zeta T_i} + \psi_{\boldsymbol{i}} + \boldsymbol{v_i + \varepsilon_{it}}$$

Where $\mathbf{P}_{it}$ is a vector of dummy variables denoting other production constraints (i.e., other unnamed diseases and shortage of grazing land or water) taking the value one if household $\boldsymbol{i}$'s livestock are affected by these production constraints at time $\boldsymbol{t}$ and zero otherwise. $\boldsymbol{X_{it}}$represents a vector of socioeconomic characteristics of households that may affect the outcome variables. $\mathbf{T}$ is a vector of time dummies denoting survey years. ψ denotes household level unobserved heterogeneity and $\boldsymbol{v_i}$ denotes unobserved district level heterogeneities. The coefficients α, β, δ, η**,** γ, ζ, and, where δ, η and γ are vectors, are population parameters to be estimated. $\boldsymbol{\varepsilon_{it}}$ is error term associated with household $\boldsymbol{i}$ at time $\boldsymbol{t}$. Our primary interest in equation (2) is the size and sign of $\boldsymbol{\beta}$ and **η**. which are estimated relative to the base category: households that did not face trypanosomiasis and other production constraints. If the incidence of trypanosomiasis increases the livestock died, cost of livestock production, food insecurity, and poverty,

$\boldsymbol{\beta}$ must be positive and statistically significant. If the incidence of trypanosomiasis reduces crop production, $\boldsymbol{\beta}$ must be negative and statistically significant. Similarly, $\boldsymbol{\eta}$ will have statistically significant on outcome variables if the impact of trypanosomiasis varies with other production constraints. For instance, $\boldsymbol{\eta}$ will have statistically significant and positive sign on value of livestock death if livestock which are affected by trypanosomiasis are more likely to die when they are also affected by other production constraints.

The incidence of trypanosomiasis tells us the proportion of households affected by trypanosomiasis and its impact, but it does not tell us the intensity of the disease. Fortunately, farming households reported the intensity of trypanosomiasis disease either as severe, moderate, or not affected at all. We estimate the intensity of trypanosomiasis on the outcome variables using equation (3) as follows:

$$(3)\quad \boldsymbol{Y_{it}} = \boldsymbol{\alpha} + \boldsymbol{\theta S_{it}} + \boldsymbol{\tau M_{it}} + \boldsymbol{P_{it}\delta} + \boldsymbol{S_{it}P_{it}}\Gamma + \boldsymbol{M_{it}P_{it}\mu} + \boldsymbol{X_{it}\gamma} + \boldsymbol{\zeta T} + \psi_{\boldsymbol{i}} + \boldsymbol{v_i} + \boldsymbol{\varepsilon_{it}}$$

where $\boldsymbol{S_{it}}$ and $\boldsymbol{M_{it}}$ represent severe and moderate intensity of trypanosomiasis respectively, and all other terms are as defined before. Our parameters of interests are $\boldsymbol{\theta}$ and $\boldsymbol{\tau}$ o be estimated, and their interpretations are similar to $\boldsymbol{\beta}$ in equation (2); whereas, Γ and $\boldsymbol{\mu}$ have interpretations similar to $\boldsymbol{\eta}$ that we saw before, except that we have now intensities of trypanosomiasis. Since the intensity of trypanosomiasis is a categorical variable with three possible outcomes, $\boldsymbol{S_{it}}$and $\boldsymbol{M_{it}}$ are measured in comparison to farming households that face no trypanosomiasis.

We estimate equations (2) and (3) using the fixed-effects estimator for dependent variables of continuous values (Wooldridge, 2010). This model allows correlation between unobserved time-invariant heterogeneities and exogenous variables. Since we are using a panel data, which allows us controlling for time-invariant unobserved heterogeneities. Unobserved time-invariant heterogeneities may arise, for instance, due to differences in managerial skills of farming households. While some households may keep and feed their livestock at home, other households may take their livestock to their own open grazing lands, and still some other households may take their livestock to common grazing lands and forests, which may increase their trypanosomiasis exposure. Households may also differ in their treatment to and follow up of their livestock: some households closely follow their livestock conditions, perhaps on daily basis, while others may not give sufficient attention to their livestock, leaving the whole responsibility to herders. Controlling for these and other unobserved heterogeneities is essential to get consistent estimates of variables of interest, which the fixed effects models handle.

The explanatory variables are selected based on empirical findings from previous studies (Do et al., 2019; Hüttner et al., 2001) and on local context. For instance, access to quality extension services may affect livestock death through advices about prevention and medication, improved livestock breeds and fodder access and feeding. Exogenous shocks such as drought, family member sickness or death may also affect the outcome variables of interest. Socio-economic and demographic characteristics of the households such as income, age, and education level of the head of the household, distance to the market, media access and income of the household may also affect outcome variables.

Measurement of dependent variables

Most of our dependent variables have zero values. Value and number of livestock death, out of pocket cost of livestock production, veterinary and medicine expenses, cow milk yield and value of crop production all have zero values. To account for this, we use the inverse hyperbolic sine transformation (IHS**)** of these variables (Bellemare & Wichman, 2020). The percentage change on IHS transformed dependent variables due to a dummy covariate equals $[\exp(\beta) - 1]$ (Bellemare & Wichman, 2020).

Moreover, since we include interaction terms of trypanosomiasis and other production constraints in the regressions, first compute the estimated marginal effects of trypanosomiasis on IHS transformed dependent variable, and then we compute [exp(ME) – 1], where ME is marginal effect. Indeed, we also consider censored models to account for the zero values, and we found that the results are similar in terms of sign and statistical significance of most of the covariates. (The results from Tobit models are not included in the paper, but can be shared up on request.) However, we preferred and presented IHS transformed variables to use fixed effects models, which allows controlling for time-invariant unobserved heterogeneities.

We also have dummy dependent variables. One of this is whether a household's livestock died in 12 months preceding the surveys or not, in that we estimated the probability of livestock death. Another dependent variable is poverty status of households, in that households are grouped in to poor if the per capita income (in adult equivalence) is less than 3,781 Ethiopian Currency Birr (ETB) using 2011 price or non-poor otherwise (NPC, 2017).

Estimating the broader implication of trypanosomiasis

To see the broader implication of trypanosomiasis on the Ethiopian livestock economy, we estimate the total economic loss due to trypanosomiasis using equation (4) as follows:

(4) $\boldsymbol{EL} = \boldsymbol{\beta} \times \boldsymbol{R} \times \boldsymbol{D} \times \boldsymbol{p}$

where $\boldsymbol{EL}$ is the country-level economic losses due to trypanosomiasis, $\boldsymbol{\beta}$ denotes the value of livestock death that households whose livestock are affected by trypanosomiasis lost relative to households whose livestock are not affected by trypanosomiasis, which is obtained from equation (2). **R** is the incidence of trypanosomiasis. We consider two incidences of the disease: the sample mean of our data, and the one by Leta et al.(2016) obtained from metal analysis. $\boldsymbol{D}$ is the number of animals died due to various factors including by trypanosomiasis obtained from the CSA Agricultural Sample Livestock Survey, and $\boldsymbol{p}$ is the weighted price of livestock.

To make economic sense of the EL, we estimate the equivalent amount of poverty reduction had the Ethiopian government earned and invested it in pro-poor social protection programs such as safety nets. The number of people that could potentially escape out of poverty if the economic loss (ΔEL) is spent on poverty reduction is estimated using equation (5) (Alene et al., 2009; Kassie et al., 2018).

(5) $$\boldsymbol{n} = \left(\frac{\mathbf{EL}}{\boldsymbol{AGDP}} \times \boldsymbol{e}\right) \times \boldsymbol{N}$$

where $\boldsymbol{n}$ is the number of people who can be lifted out of poverty, EL is the total economic losses because of trypanosomiasis. $\boldsymbol{AGDP}$ represents the agricultural gross domestic product, which equals 19,804,614,047 USD at 2011 price in 2016 that we compiled from the World Bank Data, $\boldsymbol{e}$ is the elasticity of poverty with respect to $\boldsymbol{AGDP},$ for which we use the rural income elasticity of poverty since we do not have data on the elasticity of poverty with respect to AGDP; the 2011 – 2016 the rural income elasticity of poverty is -2.106. $\boldsymbol{N}$ denotes the number of people who lives below the poverty line in rural Ethiopia, which equals 2,125,353,715 – compiled from Planning and Development Commission (NPC, 2017) and World Data.

In addition to the rural income elasticity of poverty, we also computed the number of persons that would had been lifted out of absolute poverty and of food poverty from zero income by dividing the value of livestock loss due to trypanosomiasis by the absolute poverty and food poverty lines. That is

(6) $\boldsymbol{n_1} = \left(\frac{\mathbf{EL}}{\boldsymbol{pl}}\right)$, where n1 denotes the number of absolute or food poverty persons that could be lifted out of poverty from zero income, and pl denotes the absolute poverty line or the food poverty line which are respectively 3,781 and 1,987 ETB at 2011 prices.

4. Descriptive statistics

We measure livestock death in three ways. First, households were asked about the type and number of livestock deaths in the last 12 months preceding the survey. To aggregate the different types of livestock and to adjust overtime price differences across survey years, we computed the monetary value of the livestock using the baseline survey (2011) average prices of each animal types. Second, we measure livestock death by converting the number of different types of livestock into Tropical Livestock Units (TLU)[2] using conversion factors. Finally, we measure livestock death by dummy indicating whether the household lost livestock by disease.

As shown in Table 1 about 30% of the sample reported livestock death in the last 12 months. Excluding poultry death that we exclude from all the analysis now onwards, around 20% of the households reported livestock death. They lost, on average, 0.62 livestock heads and 0.32 TLU per household per. In value terms, livestock death amounts about ETB 472 (US$ 28[3]) per household per year. These figures do not include losses due to fertility and other services of livestock. Both the number and value of livestock died substantially declined over the survey period; perhaps, because government’s and donors’ investments to improve the livestock sector.

[2] For TLU, we use 1 = cattle; 1.2 = equine and camel, 0.1 = goats and sheep.
[3] We use the 2011 price and exchange rate (1 USD = 16.899)

Regarding cow milk production, the three years average household level milk production was 97 liters, and around 32% of the households produced milk. The average milk yield per lactating cow per year (i.e., milk yield) was 149 liters. Data about the number of lactating cows is missing in the first round survey.

For the cost of livestock production, we include out of pocket expenditures for hired labor, purchased feed, livestock medication and other expenses of livestock production. The three survey years average annual (out of pocket) cost of livestock production is about ETB 186, which is very small, perhaps because we consider only out of pocket expenses. Out of this, around ETB 24 is the expense for livestock medication.

Table 1**Error! Reference source not found.** presents also the incidence and severity of production constraints. Trypanosomiasis incidence with severe impact on livestock remained fairly the same over the three survey periods, with minor reduction from 5.5% in 2011 to 4.8% in 2017. Whereas, trypanosomiasis incidence with moderate impact slightly increased from 8.0% in 2011 to 11.2% in 2017. The average incidence of trypanosomiasis over the survey years is 16.0%, which is higher than the 8.12% bovine trypanosomiasis incidence that Leta et al. (2016) found from meta-analysis; perhaps, because the result we found includes trypanosomiasis incidence on equine and camel.

Table 1. Description of outcome variables and key independent variables

Descriptions	2011	2013	2017	Total
Panel A: outcome variables				
Households who lost livestock (%)	36.8	19.5	3.8	20.0
Number of livestock heads died per household	1.14	0.58	0.12	0.61

Descriptions	2011	2013	2017	Total
Number of livestock died in Tropical Livestock Unit	0.60	0.30	0.07	0.32
Average value of livestock died per household, ETB	901	446	70	472
Value of livestock died for households who lost livestock, ETB	2448	2289	1818	2357
Milk yield (liters/cow/year)	-	229.7	90.1	149.3
Value of crop production, ETB	12683	8620	9361	10210
Out of pocket cost of livestock production (ETB)	288	94	178	186
Cost of veterinary and medicine (ETB)	-	18	30	24
Panel B: key independent variables				
1 if livestock affected by trypanosomiasis, 0 otherwise	13.5	18.6	16.0	16.0
1 if livestock severely affected by trypanosomiasis, 0 otherwise	5.5	6.1	4.8	5.5
1 if livestock moderately affected by trypanosomiasis, 0 otherwise	8.0	12.5	11.2	10.6
1 if livestock not at all affected by trypanosomiasis, 0 otherwise	86.5	81.4	84.0	84.0
1 if livestock affected by other diseases, 0 otherwise	28.0	19.9	18.3	22.1
1 if livestock affected by Grazing land shortage, 0 otherwise	44.6	42.4	43.6	43.5
Total number of households	5763	5763	5763	5763

Note: the exchange rate for Ethiopia was 16.899 ETB/US$ in 2011; data about number of lactating cows that households owned was not collected in the 2011 survey.

Unconditional correlations between outcome variables and trypanosomiasis

Figure 1 presents the average value of livestock died (except poultry since trypanosomiasis does not affect poultry) in the sample, disaggregated by trypanosomiasis severity. The results show a clear positive correlation between the severity of trypanosomiasis and the value of livestock died: households whose livestock were severely affected by trypanosomiasis loss almost double (97%) value of livestock (867 ETB) than households whose livestock were not affected by trypanosomiasis (441 ETB). Overall, households whose livestock are affected by the disease (regardless of its severity) lost 45% more value of livestock death than households whose livestock are not at all affected by the disease, and the mean difference is statistically significant at <0.1% level of significance.

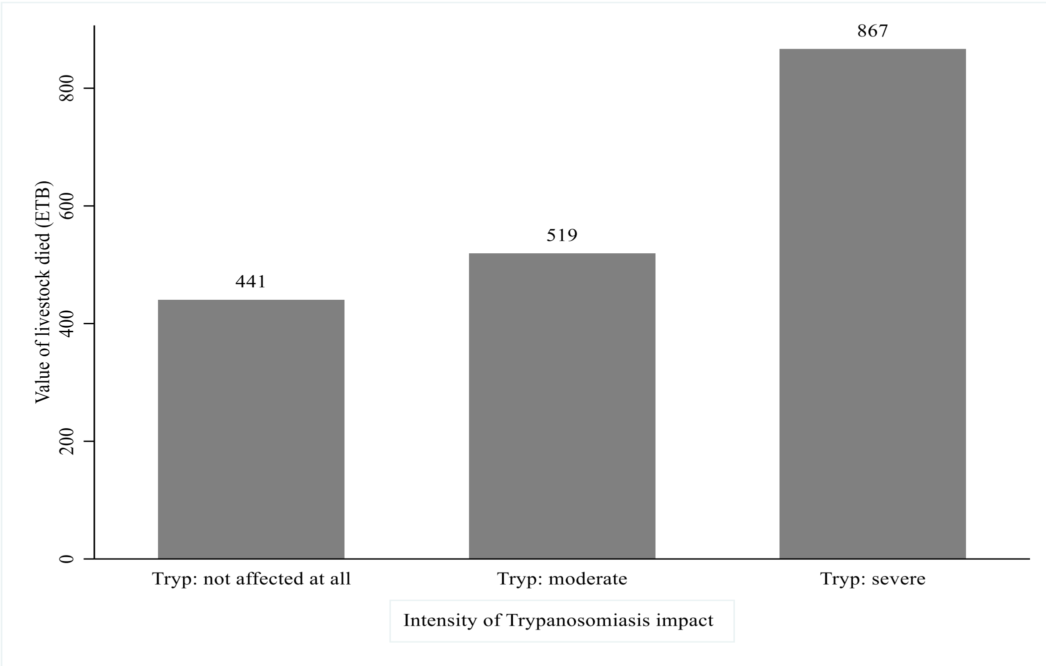

Figure 1. Value of livestock died by trypanosomiasis intensity

Figure 2 presents cost of livestock production, disaggregated by severity of trypanosomiasis. The results indicate that cost of livestock production increases substantially with the severity of trypanosomiasis. Specifically, households whose livestock are severely affected by the disease incurred around 43% more cost of livestock production than households whose livestock are not affected by the disease. Disregarding the severity of the disease, we also compared cost of livestock production between affected and non-affected by trypanosomiasis households. We found that the former incurred around 27% more cost of livestock production than the latter, and the mean difference is statistically significant at <0.1% level of significance.

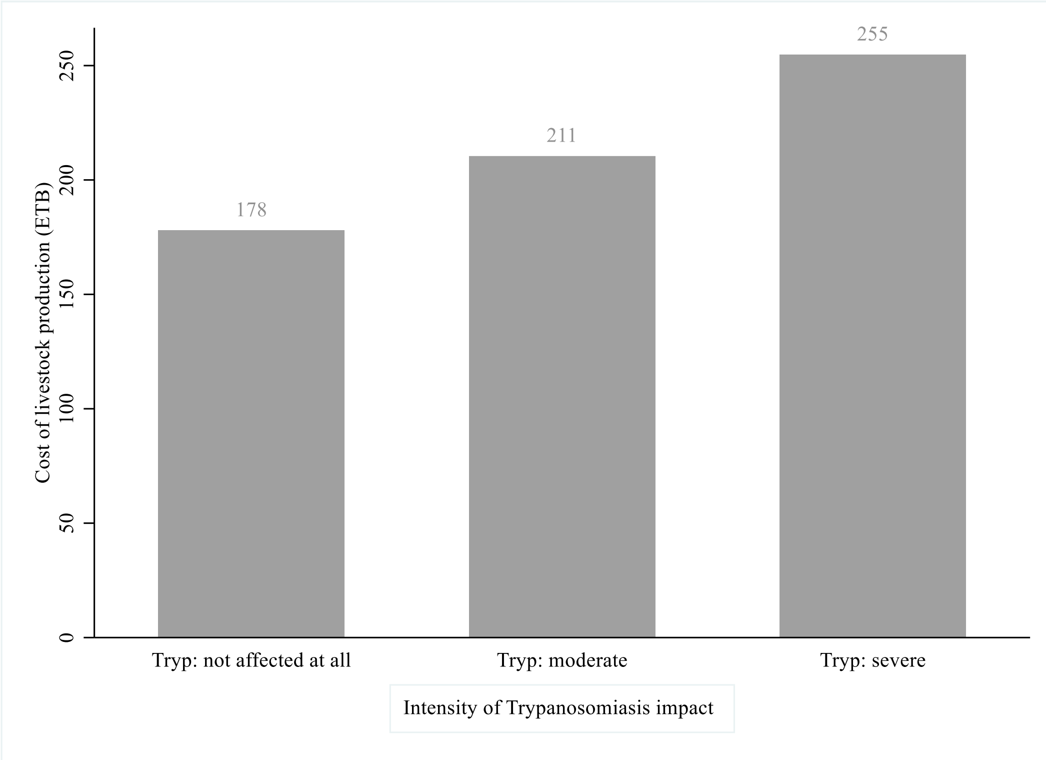

Figure 2. Cost of livestock production, disaggregated by the intensity of trypanosomiasis

We next examine the correlation between milk yield (liters/cow/year) and the severities of trypanosomiasis. The results presented in Figure 3 show that households whose livestock were severely affected by the diseases obtained the lowest amount of milk yield while households whose livestock were moderately affected by the diseases obtained the highest yield. The latter result is unexpected. Moreover, we do not also find statistically significant milk yield difference between households whose livestock are affected and not affected by the disease.

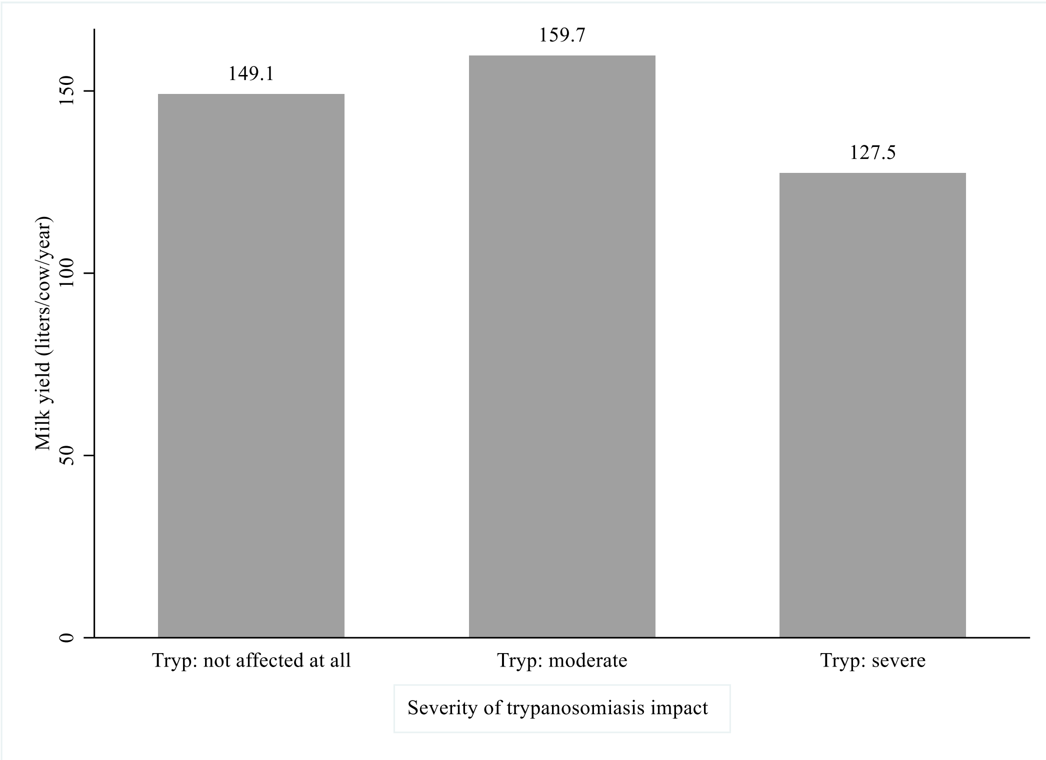

Figure 3. Milk produced (liters) per lactating cow, disaggregated by the intensity of trypanosomiasis

Figure 4 presents value of crop production disaggregated by trypanosomiasis severity. Similar to the milk yield result, households whose livestock are severely affected by the disease obtained the lowest value of crop production. However, unexpectedly, households whose livestock are moderately affected by the disease earned the highest crop value. Moreover, we do not also find statistically significant value of crop production difference between households whose livestock are affected and not affected by the disease.

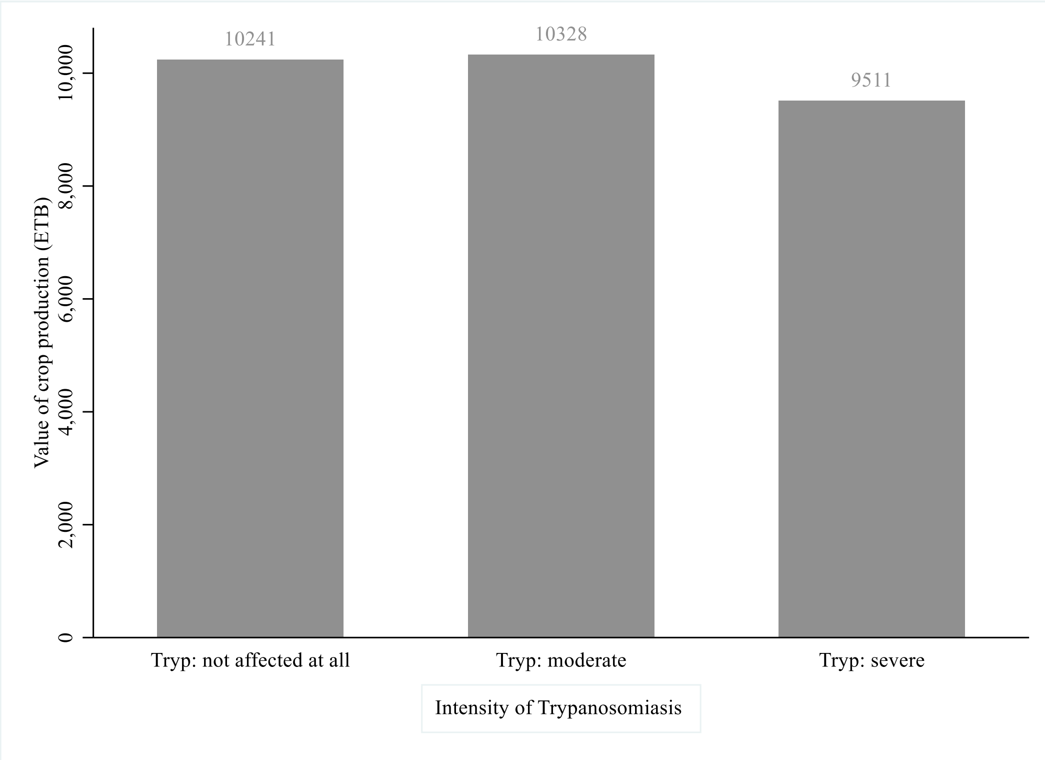

Figure 4. Value of crop production, disaggregated by the intensity of trypanosomiasis

The above results reveal that the livestock sector's economic performance suffers from trypanosomiasis. However, these are unconditional mean results that may not only be caused by these factors. For instance, there are other diseases reported by farmers that may drive the losses. Rigorous analysis of the effect of trypanosomiasis after accounting for other variables remains crucial. The next section presents the empirical results.

5. Empirical results and discussion

This section presents the empirical findings. We present the impact of both the incidence and severity of trypanosomiasis on outcome variables including livestock death (measured in value terms, TLUs and as a probability of livestock death in 12 months preceding the survey periods), milk yield, cost of livestock production, veterinary and medicine expense and on poverty. We also present the impact of trypanosomiasis on the wider economy as measured by the number of persons who would had been lifted out of poverty had the country avoided livestock death because of trypanosomiasis.

5.1.The impact of trypanosomiasis incidence on livestock production

Table 2 presents the impact of trypanosomiasis incidence on outcome variables of interest. All the dependent variables except the probability of livestock death are inverse hyperbolic sine transformations (IHS) to account for zero values, and are estimated using fixed effects linear model. Whereas, we estimated the probability of livestock death using the (Chamberlain, 1980; Mundlak Y., 1978) pseudo fixed effects logit model.

The results in columns 2 to 4 present the impacts of trypanosomiasis incidence and other covariates on livestock death. The results consistently show that production constraints, namely, trypanosomiasis, other unnamed diseases, shortage of grazing land or water, and the interactions of these production constraints have statistically significant and positive impacts on value of livestock death. Overall, households whose livestock are affected by trypanosomiasis loss about 83% more value of livestock death than households with no trypanosomiasis incidence. If we compare the value of livestock death of households whose livestock are not affected by any of the three production constraints with households whose livestock are affected by trypanosomiasis, the latter loss about 214% more value of livestock death than the former, ceteris paribus. Households whose livestock are affected by both trypanosomiasis and all other diseases combined loss the highest percentage (620%) value of livestock death, ceteris paribus. In terms of the number of livestock died in TLUs (column 3), trypanosomiasis incidence increases livestock death by about 9%. Consistently, trypanosomiasis incidence also increases the probability of livestock death as shown in column 4 of Table 2.

Regarding the impact on milk yield, the results (column 5) show that trypanosomiasis has statistically significant (though at 10% level of significance) and negative impact on milk yield. Computing the marginal effect of trypanosomiasis after accounting for the IHS transformation of the dependent variable show that milk yield is lower by about 69% for households where there is trypanosomiasis incidence, ceteris paribus. However, the interaction terms among trypanosomiasis, other unnamed diseases and shortage of grazing land or water as well as the last two production constraints individually do not have statistically significant impacts on milk yield.

The last two columns present the impact of trypanosomiasis incidence on (out of pocket) cost of livestock production and on veterinary and medicine expenses. The results show that households whose livestock are affected by trypanosomiasis incur around 69% and 100% higher cost of livestock production and veterinary and medicine expenses respectively than households whose livestock are not affected by the disease, ceteris paribus.

Table 2. The impact of trypanosomiasis incidence on livestock death, milk yield & cost of livestock production

Covariates	Value of livestock died (IHS)	No. of livestock died in TLU (IHS)	Probability of livestock death	Milk per lactating cow per year (IHS)	Cost of livestock production (IHS)	Cost of veterinary & medicine (IHS)
Trypanosomiasis incidence	1.145*	0.167*	0.921***	-1.778+	0.995**	1.053***
	(0.340)	(0.053)	(0.204)	(0.948)	(0.246)	(0.238)
Trypanosomiasis + shortage of grazing land or water	0.519**	0.075**	0.549***	-0.312	1.320***	1.048***
	(0.128)	(0.021)	(0.103)	(0.534)	(0.153)	(0.141)
Trypanosomiasis + other diseases	1.975***	0.305***	1.360***	-2.413	1.120***	1.717***
	(0.371)	(0.072)	(0.205)	(1.694)	(0.246)	(0.408)
Trypanosomiasis + other diseases + shortage of grazing land or water	0.376**	0.062**	0.519***	-0.209	0.555**	0.440*
	(0.109)	(0.017)	(0.095)	(0.377)	(0.154)	(0.149)
Shortage of grazing land or water	0.179+	0.018	0.242**	-0.220	0.749***	0.259*
	(0.094)	(0.015)	(0.071)	(0.326)	(0.102)	(0.088)

Other diseases	1.292***	0.185***	1.008***	-0.284	1.143***	1.261***
	(0.186)	(0.037)	(0.115)	(0.808)	(0.171)	(0.222)
Other diseases + shortage of grazing land or water	1.039*** (0.128)	0.186*** (0.024)	0.866*** (0.088)	0.642 (0.431)	1.387*** (0.120)	1.052*** (0.131)
Household characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Socio-econmics characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Extension service and media access	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Mundlak fixed effects			Yes			
Constant	-1.594***	0.126*	-1.904***	3.627***	1.156***	0.074
	(0.391)	(0.045)	(0.141)	(0.796)	(0.236)	(0.212)
lnsig2u			-1.862***			
			(0.476)			
Observations	17,251	17,251	17,251	3,217	17,251	11,508

R-squared	0.201	0.158		0.170	0.165	0.103
chi2			1198.766			

District (Woreda) clustered standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.001, *** p<0.0001

5.2.The impact of trypanosomiasis intensity on livestock production

The regression equations presented in this section are similar to the ones we saw above except that we disaggregate in this section the impact of trypanosomiasis by its severity. Table 3 presents regression results.

The results show that all of the coefficients of severe trypanosomiasis incidence and its interaction terms with other production constraints are statistically and economically significant on all the three measures of livestock death. Overall, households whose livestock are affected severely and moderately by trypanosomiasis respectively loss around 158% and 51% more value of livestock death than households whose livestock are not affected at all by the diseases. The coefficients of severe and moderate trypanosomiasis show that households whose livestock are affected by the disease loss about 351% and 150% more value of livestock death than households whose livestock are not affected by any of the three production costs, ceteris paribus. Severe trypanosomiasis coupled with other unnamed diseases cause the highest percentage (882%) loss of value of livestock death. One unexpected result is the statistical insignificance of the coefficient on both value and number of livestock death of moderate trypanosomiasis incidence interacted with other diseases and shortage of grazing land or water.

The results show also that severe trypanosomiasis incidence and its interaction terms with other production constraints severely affect milk yield while we do not find statistically significant impact of moderate incidence of the diseases on milk yield. Overall, milk yield is lower by about 78% for households whose livestock are severely affected by the disease. Severe trypanosomiasis incidence coupled with other diseases resulted in the highest impact on milk yield, 99% reduction, ceteris paribus.

On the other hand, moderate trypanosomiasis and its interactions with other production constraints have statistically significant and positive impacts on cost of livestock production including on veterinary and medicine expenses while severe incidence of the disease and its interactions with other production constraints do not have consistent results on cost of livestock production cost. Perhaps, it could be that severely affected livestock are too weak to consume fodder and to demand more labor while moderately affected livestock need more fodder to recover and they need labor to treat them.

Table 3. The impact of trypanosomiasis intensity on livestock death, milk yield & cost of livestock production

Covariates	Value of livestock died (IHS)	No. of livestock died in TLU (IHS)	Probability of livestock death	Milk per lactating cow per year (IHS)	Cost of livestock production (IHS)	Cost of veterinary & medicine (IHS)
Severe trypanosomiasis	1.506*	0.244*	1.159**	-1.992*	0.748	0.758+
	(0.652)	(0.114)	(0.345)	(0.997)	(0.465)	(0.421)
Severe trypanosomiasis + other diseases	2.285**	0.411***	1.435***	- 4.729***	0.531	-0.179
	(0.611)	(0.091)	(0.357)	(0.524)	(0.353)	(0.670)
Severe trypanosomiasis + shortage of grazing land or water	0.711*	0.126*	0.675**	-1.416+	1.311***	1.105***
	(0.223)	(0.039)	(0.174)	(0.784)	(0.246)	(0.218)
Severe trypanosomiasis + other diseases + shortage of grazing land or water	0.925***	0.148***	0.771***	0.600	0.606*	0.278
	(0.173)	(0.031)	(0.119)	(0.545)	(0.220)	(0.189)
Moderate trypanosomiasis	0.918*	0.118*	0.767***	-1.614	1.145***	1.246***

	(0.304)	(0.046)	(0.188)	(1.427)	(0.224)	(0.299)
Moderate trypanosomiasis + other diseases	1.757**	0.228*	1.309***	-1.638	1.577***	2.533***
	(0.511)	(0.101)	(0.291)	(2.074)	(0.370)	(0.600)
Moderate trypanosomiasis + shortage of grazing	0.435*	0.051*	0.484**	0.384	1.323***	1.020***
land or water	(0.158)	(0.025)	(0.131)	(0.614)	(0.158)	(0.166)
Moderate trypanosomiasis + other diseases +	0.105	0.020	0.371*	-0.531	0.528*	0.511*
shortage of grazing land or water	(0.126)	(0.019)	(0.117)	(0.474)	(0.175)	(0.196)
Other diseases	1.303***	0.187***	1.011***	-0.327	1.144***	1.258***
	(0.186)	(0.037)	(0.116)	(0.821)	(0.171)	(0.219)
Shortage of grazing land or water	0.178+	0.018	0.243**	-0.208	0.749***	0.260*
	(0.094)	(0.015)	(0.071)	(0.328)	(0.102)	(0.088)
Other diseases + shortage of grazing land or water	1.040***	0.186***	0.867***	0.691	1.386***	1.044***
	(0.128)	(0.023)	(0.088)	(0.438)	(0.120)	(0.130)
Household characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Socio-econmics	Yes	Yes	Yes	Yes	Yes	Yes

characteristics						
Extension service and media access	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
Mundlak effect			Yes			
Constant	-1.613*** (0.394)	0.124* (0.045)	-1.914*** (0.141)	3.636*** (0.765)	1.153*** (0.236)	0.077 (0.213)
lnsig2u			-1.806*** (0.457)			
Observations	17,251	17,251	17,251	3,217	17,251	11,508
R-squared	0.202	0.160		0.177	0.165	0.105
chi2			1272			

Cluster (woreda) standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.001, *** p<0.0001

5.3.Trypanosomiasis impact on crop production

Table 4 presents the impact of trypanosomiasis on crop production where the latter is measured in value terms so as to aggregate all types of crops that the farmers produce. We present the results from fixed effects linear regression where the dependent variable is IHS transformed to account for zero value because of total crop failure and from Mundlak – Chamberlin random effect Tobit model. We consider also the impact of both the incidence of trypanosomiasis and its intensity in both models.

The results from both the FE and Tobit models show that severe trypanosomiasis coupled with shortage of grazing land or water has statistically and economically significant negative impact on crop production. The result from the FE model shows that households whose livestock are severely affected by trypanosomiasis and by shortage of grazing land or water earn about 26.1% less value of crop production than households whose livestock are not affected by any of the three livestock production constraints, ceteris paribus. However, the results from the FE models show that most of the incidence and intensity of trypanosomiasis and their interaction terms with other livestock production constraints do not have statistically significant effects on value of crop production. Whereas most of these variables have statistically significant effects in Tobit model.

Table 4. The impact of trypanosomiasis on value of crop production (Ethiopian currency)

Covariates	Fixed effects model (FE)	Mundlak – Chamberlin random effect Tobit model

Trypanosomiasis incidence	0.152 (0.105)		-816 (796)	
Trypanosomiasis incidence + shortage of grazing land or water	-0.070 (0.095)		-1496 * (476)	
Trypanosomiasis incidence + other diseases	0.186 (0.272)		138 (1174)	
Trypanosomiasis incidence + other diseases + shortage of grazing land or water	-0.062 (0.072)		-1626 *** (354)	
Severe trypanosomiasis incidence		0.186 (0.155)		-24.02 (1277)
Severe trypanosomiasis + shortage of grazing land or water		-0.303* (0.105)		-3049 ** (815)
Severe trypanosomiasis + other diseases		0.361 (0.291)		-3428 + (1799)
Severe trypanosomiasis + other diseases + shortage of grazing land or water		-0.082 (0.095)		-2010 ** (571)
Moderate trypanosomiasis		0.136		-1293

		(0.120)		(998)
Moderate trypanosomiasis + shortage of grazing land or water		0.041		-776
		(0.110)		(566)
Moderate trypanosomiasis + other diseases		0.050		2728 +
		(0.315)		(1539)
Moderate trypanosomiasis + other diseases + shortage of grazing land or water		-0.051		-1432 **
		(0.076)		(420)
Shortage of grazing land or water	-0.113*	-0.113*	-1012***	-1013***
	(0.051)	(0.051)	(250)	(250)
Other diseases	0.029	0.029	-257	-264
	(0.083)	(0.083)	(461)	(460)
Other diseases + shortage of grazing land or water	-0.154+	-0.153+	-1184 *	-1187 *
	(0.078)	(0.078)	(397)	(397)
Production inputs	Yes	Yes	Yes	Yes
Household socio-economics characteristics	Yes	Yes	Yes	Yes

Destric effects			Yes	Yes
Time dummies	Yes	Yes	Yes	Yes
Extension service and media access	Yes	Yes	Yes	Yes
Mundlak fixed effects			Yes	Yes
Constant	6.124***	6.123***	-	-
	(0.202)	(0.202)	8488***	8490***
			(653)	(653)
sigma_u			4731	4722
			***	***
			(156)	(156)
sigma_e			11870	11868
			***	***
			(80)	(80)
Observations	17126	17126	17126	17126
R-squared	0.208	0.208		
chi2			3829	3846

Clustered standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.001, *** p<0.0001

5.4.Trypanosomiasis impact on poverty

We next examine the impact of trypanosomiasis on absolute poverty status of households, where we use the Ethiopian Central Statistics Agency poverty line to determine the absolute poverty status of the households. To account for intra-household age differences among the household members, we use effective adult equivalent. We present the impact of both the share of livestock died and trypanosomiasis incidence and intensities. The results presented in Table 5 are all from Mundlak – Chamberlin random effects logit model.

The results presented in the second column show that the probability of falling below the poverty line increases with the share of livestock dead. This is intuitive since households losing more value of livestock due to diseases earn less income from livestock and livestock products sales. By increasing the value of livestock death as we saw before, trypanosomiasis, thus, indirectly increases the probability of falling below poverty line.

The results in columns 3 and 4 present the direct effects of trypanosomiasis incidence and intensities on probability of being poor. The results show that severe trypanosomiasis incidence and its interaction with shortage of grazing land or water increases the likelihood of households falling below poverty line. Similarly, trypanosomiasis incidence and its interaction with shortage of grazing land or water increases the likelihood of households falling below poverty line. We do not find statistically significant effects on the rest of the trypanosomiasis dummies, however.

Table 5 The impact of trypanosomiasis on poverty

Covariates	Mundlak – Chamberlin random effects

	logit model		
Share of value of livestock died	0.448*		
	(0.146)		
Trypanosomiasis incidence		0.012	
		(0.175)	
Shortage of grazing land or water		0.125	
		(0.077)	
Other diseases		-0.038	
		(0.121)	
Trypanosomiasis + shortage of grazing land or water		0.247+	
		(0.136)	
Trypanosomiasis + other diseases		0.027	
		(0.318)	
Trypanosomiasis + other diseases + shortage of grazing		0.147	
land or water		(0.134)	
Other diseases + shortage of grazing land or water		-0.128	
		(0.103)	
Severe trypanosomiasis			-0.248
			(0.262)
Severe trypanosomiasis + shortage of grazing land or water			0.631*
			(0.230)

Severe trypanosomiasis + other diseases			0.526
			(0.452)
Severe trypanosomiasis + other diseases + shortage of grazing land or water			0.151 (0.140)
Moderate trypanosomiasis			0.169
			(0.198)
Moderate trypanosomiasis + shortage of grazing land or water			0.075 (0.125)
Moderate trypanosomiasis + other diseases			-0.334
			(0.366)
Moderate trypanosomiasis + other diseases + shortage of grazing land or water			0.145 (0.163)
Household characteristcs (demography, socio-economics)	Yes	Yes	Yes
Destric effects	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes
Extension service and media access	Yes	Yes	Yes
Mundlak fixed effects	Yes	Yes	Yes
Constant	0.103	0.140	0.140
	(0.217)	(0.213)	(0.213)
/			
lnsig2u	-0.169	-0.169	-0.169
	(0.122)	(0.121)	(0.121)

Observations	17251	17251	17251
chi2	466.014	617.447	657.982

Cluster standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.001, *** p<0.0001

5.5.Broader implication of trypanosomiasis

To understand the broader impact of the diseases, we computed the value of livestock lost due to trypanosomiasis. To compute the value, we used the coefficient of the disease that we estimated before, the average number of livestock that the country lost in the three survey years and the 2011 producer price of livestock. As stated before, the three years average incidence of trypanosomiasis in our sample is 16%; whereas, Leta et al. (2016) found 8.12% average trypanosomiasis incidence. We use both incidences and we compute wider economy implications of the disease as discussed from equation 4 -6 in the empirical specification section. The results are presented in Table 6.

The results show that Ethiopia roughly lost from around 1.12 billion ETB (66.4 million USD) to 2.13 billion ETB (125.8 million USD), depending on which trypanosomiasis incidence we use, worth of livestock value due to trypanosomiasis. This lost income due to trypanosomiasis would had lifted from 15 million to 28.4 million rural persons out of poverty when we use the rural income elasticity of poverty (using equation 5). Similarly, this lost income would had lifted from 562,446 to 1.1 million persons out of food poverty, and from 296,562 to 584,360 persons out of absolute poverty from zero income (using equation 6). Note that the substantial difference between the estimates based on equations (5 and 6) is that, while the estimates from equations (5) presents the number of persons that would had been lifted out of poverty from the current income they have, estimates from equation (6) gives the number of persons that would had been lifted out of poverty from zero income.

Table 6. Economic wide impact of trypanosomiasis using 2011 price

Variables	Trypanosomiases incidence	
	Our data sample average = 16.0	Leta et al. (2016) estimate = 8.12
Value of livestock lost ETB (Equation (4))	2.13 billion	1.12 billion
Value of livestock lost USD ETB (Equation (4))	125.8 million	66.4 million
No. of persons that would had been lifted out of poverty (computed as in equation 6 – elasticities)	28.4 million	15.0 million
No. of persons that would had been lifted out of absolute poverty from **zero income** (computed as in equation 5)	584,360	296,562
No. of persons that would had been lifted out of absolute poverty **from zero income** (computed as in equation 5)	1.1 million	562,446

These all figures indicate that trypanosomiasis is resulting in significant damage on the economy. Indeed, the disease also affect human health, which we do not account for. These estimates do not include also other costs of trypanosomiasis including the impact on cost of livestock production, fertility of livestock, on livestock products including milk and meat, and on crop production loss.

Thus, stakeholders who aim at improving livestock production and productivity need to pay great attention to the disease.

6. Conclusion

Empirical studies show that improving agricultural productivity and integrated rural development interventions are the gateways to improve the living conditions of the poor. Food and nutrition security is strongly linked to the livestock sector as it provides easy access to eggs, milk, and meat. However, the sector has been facing severe production constraints including diseases and shortage of feed and water, resulting in high mortalities and low productivity in Sub-Saharan Africa. Quantifying the extent of the production constraints' impacts is key entry points for policymakers who aim at improving the sector. This study investigated the impact of one of the main livestock diseases in Sub-Saharan Africa, trypanosomiasis, on livestock death, milk yield, on cost of livestock production, crop production, and its broader economic implications.

We used a large, three rounds panel data of 5,763 households surveyed from the largest four regions of Ethiopia, constituting the most important agricultural production areas. Suitable for rigorous investigation of the dynamics of livestock production and production constraints, the data have rich information about smallholder farming and livestock production as well as detailed socioeconomic characteristics of the households. We analyzed the data using fixed effects models which allows controlling for time-invariant household- and district- level unobserved heterogeneities.

Our estimates from the conservative fixed effects models show that households whose livestock are affected by diseases loss 83% more value of livestock death, incur 69% higher out-of-pocket cost of livestock production and pay 100% higher money for veterinary and medicine. Moreover, we found that the disease reduces cow milk yield 69%. In addition to this, households whose livestock are severely affected by trypanosomiasis and by shortage of grazing land or water earn about 26.1% less value of crop production than households whose livestock are not affected by any of livestock production constraints, ceteris paribus. The impacts of the disease substantially increase by the severity of the disease.

Analysis of broader implications of trypanosomiasis show that Ethiopia roughly lost from around 1.12 billion ETB (66.4 million USD) to 2.13 billion ETB (125.8 million USD) worth of livestock value due to trypanosomiasis. This lost income would have lifted from 15 million to 28.4 million rural persons out of poverty from their current income level.

These results show that diseases remain key livestock production constraint in Ethiopia. Thus, stakeholders who aim at improving livestock production and productivity need to pay great attention to livestock diseases. For instance, livestock extension workers could be better trained about livestock diseases and deliver better service. Our data shows that around 49% of the households were not visited by extension workers in the last 12 months preceding surveys, and worrisomely, of those visited by extension workers, only around 13% of them are satisfied by the last three visits of extension workers.

This paper is not without limitation. The first main limitation of the paper is on the analysis of the impact of diseases on milk yield. We compared milk yield between households whose any livestock (e.g., could be horse) are affected by diseases versus households whose livestock are not affected by the disease. This may underestimate the true impacts of the diseases. Future studies need to compare milk production between affected and non-affected cows. Moreover, to compute the broader implication of the disease, we assume that our samples are representative. However, our data do not include samples from pastoral areas and regions including Afar, Benishangul Gumuz, Gambella, Harari and Somalia. These areas area relatively warm and suitable for tse-tse-fly that transmits trypanosomiasis. Indeed, studies found the highest trypanosomiasis incidence in Benishangul Gumuz. Thus, our results may underestimate the true impact of the diseases. Future studies need to use national representative data to find more precise estimates about the diseases.

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